CHAPTER 125

TRANSPORT MECHANISM IN TIDAL DUNES

by Horst Nasner[x]

I. Preliminary Remarks

An interesting question arising within the scope of the further development of the German tidal rivers Elbe and Weser, is whether tidal dunes or sand waves will be formed after the navigation channel deepenings and that the success of the development measures will thus be partially or fully undone. In order to be able to better assess the formation and regeneration of these large patterns after dredging, heightened knowledge of the sand transport in a tidal dune field is necessary. A possibility of investigating the sand transport in a tidal river with pronounced tidal dunes in the field, can be realized by measurings with luminaries or tracers. The advantage of investigations in the field is, that all laboratory required scale effects are eliminated. The more difficult measuring comprehension of the course of the test in prototype must be solved through purposefully planned investigation programs.

Subsequent to observations of many years standing, on behavior of four tidal dune areas in the navigation channel of the Weser River estuary (6), investigations were carried out with luminaries above reach 1 (Fig. 1) from September till November 1974. The aim was, to obtain information on the transport mechanism for tidal dunes and heightened knowledge on the causes of regeneration after dredging.

II. Execution of the Investigations in the Field

A. The Investigation Area

The sand wave stretch in the straight section of the lower Weser River between km 27.5 and km 28.0 was fixed for the luminary measurings. As shown by earlier investigations, the large dunes in this area are approximately two-dimensional. Their crests and troughs run perpendiculary to the flow direction in the navigation channel (6). The longitudinal profile was determined by the navigation line. In order to be able to undertake the locality determination for the longitudinal soundings required for the waterway survey, double markers have been erected by the Waterways Administration at intervals of about 500 meters on both shores of the Weser. The profile of the Weser bottom in the axis of the navigation channel in the investigation area after various soundings in 1974,

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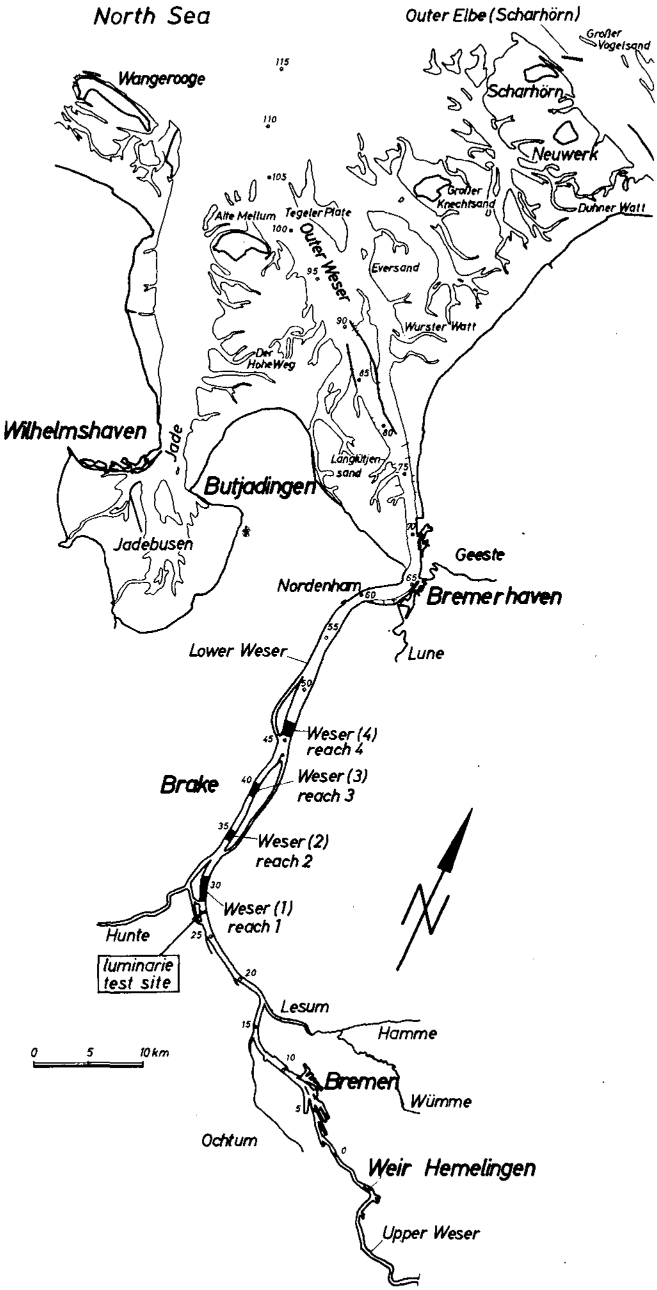


Fig. 1 Weser River with Luminarie Test Site

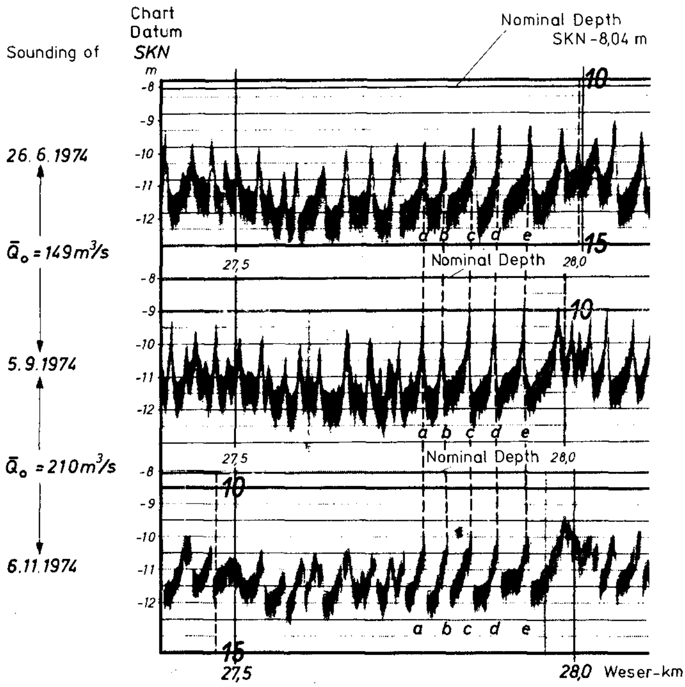
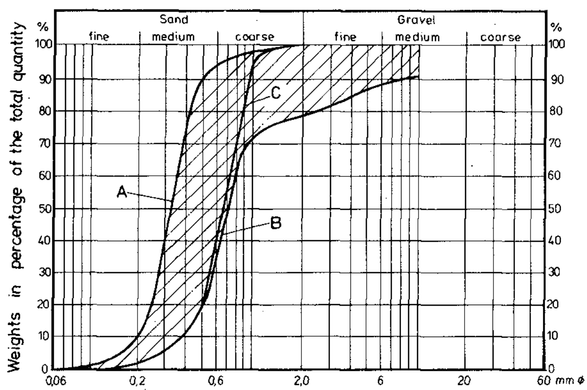


Fig. 2 Ecograph Recordings of the Weser River Bottom



A to B: Grain curve strip of core sample 12

C: Grain distribution curve of the test material

Fig. 3 Grain Distribution Curves

is depicted in Fig. 2. In order to facilitate the locating of the sand waves for the measurings, the position of five sand wave crests and six sand wave troughs was additionally fixed by double markers on the shore of the Weser River on 29th August1974. As the large dunes change their form only insignificantly in the tidal current rhythm and migrate over a long period of time very slowly in ebb current direction, contingent on the fresh water discharge Q_O of the Weser (the greater Q_O is, the higher is the transport velocity u (6), the additional reference markers were of valuable assistance in carrying out the planned soundings.

B. The Investigation Program

On 29th August 1974, about 1 m^3 of sand was taken from the crest zone of sand wave c (Fig. 2) and subsequently prepared for the investigations. A grain distribution curve for the dyed sand has been depicted in Fig. 3. A very uniform sand (d_{50} = 0.65 mm, d_{90}/d_{10} = 2.44) is concerned here. The test material was dyed two different colors (yellow and orange) and packed into sacks of water-soluble material.

On 18th September 1974, the dyed sand was deposited into a grabber on an anchored ship and quickly placed on the luff slopes of sand wave b (orange) and about 40 m below at c (yellow) in the crest zones, in mid-navigation channel (Fig. 4).

As a result of the packing, it was ensured that none of the sand material would enter a state of suspension before reaching the bottom. On the following days (19/9 and 20/9/74), two and four tides later, the first 9 core extractions were carried out from an anchored vessel with a Senkowitsch probe. The core diameter was 7 cm.

In order to disturb the river bed as little as possible in the area of the sand placing points (at b and c) the core samples were taken at sand waves d and e (Fig. 4). The crest of sand wave d was about 40 m from the location where the yellow dyed sand had been placed and about 90 m distant from sand wave crest b (orange). The crest of sand wave e lay a further 50 meters below d.

In order to create as little danger as possible for ship traffic, the soundings at d and e on the 19th and 20th September 1974 were taken up to 8 m beyond the navigation line. On 22nd and 23rd October 1974, 8 further core extractions were executed at sand waves e and d up to about 15 m beyond the navigation line. The taken bed material was investigated sectionwise (5 cm and 10 cm) for the grain composition and luminaries present.

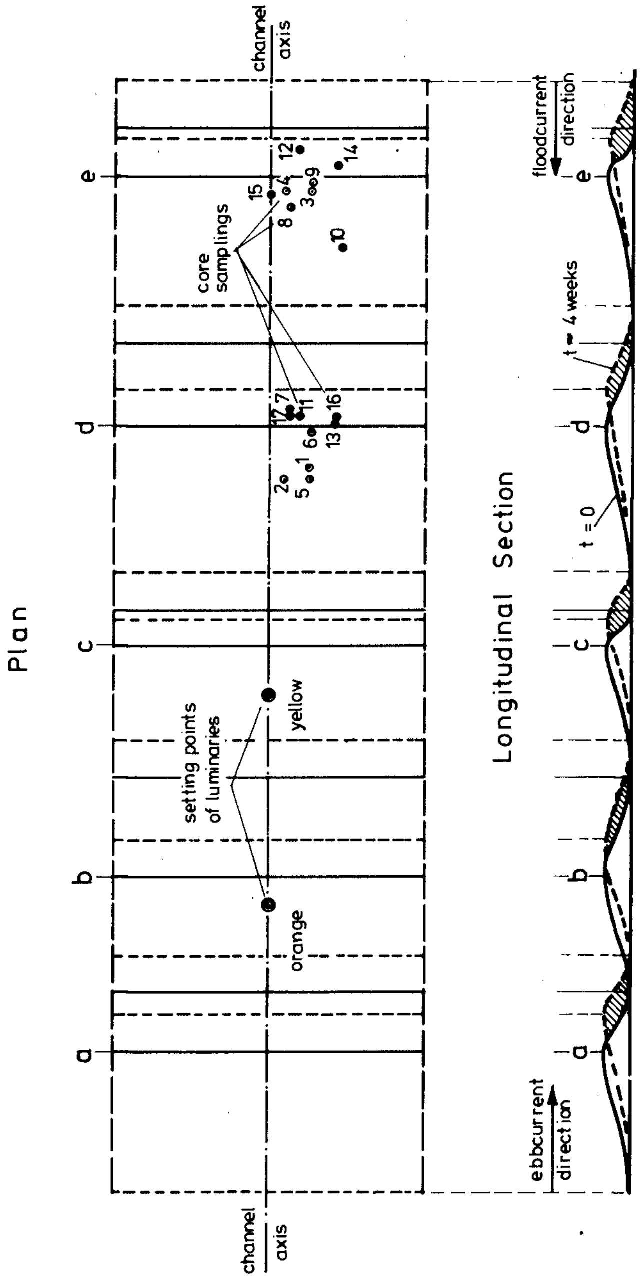


Fig. 4 Location of the placed Luminaries and the Core Sampling Points

In a further operation with a soil grabber on 4th November 1974 in a limited investigation area, upstream to Weser-km 25.5 and downstream to Weser-km 30.0, samples were taken in the navigation line from the surface of the Weser bottom. Subsequently, it was ascertained whether and how many luminaries were present in the soil samples.

III. Investigation Results

A. Tidal and Fresh Water Conditions in the Investigation Period

No storm tides occurred during the investigation period. The mean range of tide in the test area is app. 3.35 m, the mean water depth about 10 m and the mean ebb current velocity app. 100 cm/s.

All measuring operations were executed at low tide.

The mean fresh water $\bar{Q}_o$ between the measurings is compiled in the following:

29/8/1974	Taking of the test material
18/9/1974	Start of the investigations
19/20/9/1974	Core sampling (CS 1 to CS 9)
	$\bar{Q}_o$ (29/8 to 18/9/1974) = 131 m^3/s
22/23/10/1974	Core sampling (CS 10 to CS 17)
	$\bar{Q}_o$ (19/9 to 21/10/1974) = 144 m^3/s
4/11/1974	Taking of soil samples
	$\bar{Q}_o$ (22/10 to 3/11/1974) = 429 m^3/s

According to earlier investigations, at such low fresh water as was the case at the end of October 1974, the sand waves migrate in ebb current direction only very slowly (up to about 20 cm/day) (6). The mean migration velocity of the large tidal dunes in the investigation area was about 50 to 70 cm/day for $\bar{Q}_o$ = 429 m^3/s from 22/10 to 3/11/1974.

Dredging was not carried out in the test field in the period between 29/8/1974 and 4/11/1974.

B. Core Extractions

1. Luminaries

A total of 63 luminaries were found in the up to app. two meter long core extractions (CS 1 to CS 9, Fig. 4), of 19th and 20th September 1974, of which 36 (57 %) were yellow and 27 (43 %) orange. This result was not surprising, as the placing point of the yellow material lay a sand wave length closer to the extraction position. According to the evaluation of the samples taken on 19th and 20th September 1974, luminaries were found at sand wave d down to a depth of 0.30 m, and 50 m below at sand wave e, to a depth of 0.10 m.

Soundings of the Weser River bottom on 25/9/1972 during a full tidal current period and at a spring tide range of 405 cm, showed a displacement of the sand wave crests of an average 2.0 m in the tide current direction for the Weser area of km 28.4 to km 30.9. The average sand wave height at the time of the turning of the high tide K_f was 11 cm higher in the mean, than at the turning of the low tide K_e. In contrast to laboratory tests (1), the geometry of the tidal dunes in the field remains unchanged during alternating tidal currents (8). The explanation for the height increase of the sand waves in the Weser is, that the steeper lee slope is levelled off by the flood current and the thereby eroded material is deposited on the luff side. The local redistribution of the sand waves during the tidal movement clears up the question, why the luminaries were found in the extracted cores up to 0.3 m below the sand wave surface, one and two days after they had been placed.

The core samples taken on 22nd and 23rd October 1974 were intended to give information on the long-term resultant redistribution of the bed material in ebb current direction. A total of 138 were found in the 8 core samples (CS 10 to CS 17, Fig. 4), of which 80 (58 %) were yellow and 58 (42 %) orange. The number of luminaries found in the samples of only 7 cm diameter is of minor significance as compared to the fact, that the investigation material was found at greater depths in six of eight cores. Luminaries were present in core sample CS 12 down to 1.80 m below the surface of the sand wave. The only explanation for this is, that in the resulting wandering of the sand wave in ebb current direction, the dyed sand was deposited on the lee side. A similar result was brought about by theoretical considerations for directionally steady current (2,3,4), according to which the sand transport is effected in a sand wave field through erosion of the luff slopes and alluvium on the lee side in short distance transport. In Fig. 5, the distribution of the luminaries found at 10 cm intervals in the core sample CS 12 taken from sand wave e, is depicted. The luminaries are spread over the entire length of the core, as was also the case with the other samples. The number of luminaries present in the 10 cm long cylinder pieces, fluctuates between 2 and 8. Conclusions can be drawn only with reservations and without claim to general acceptance, because of the low number. It is therefore conceivable for example, that the section-wise alternating quantity of luminaries, is traceable to differing tidal and current conditions in the time from 18/9/1974 (placing of the material)

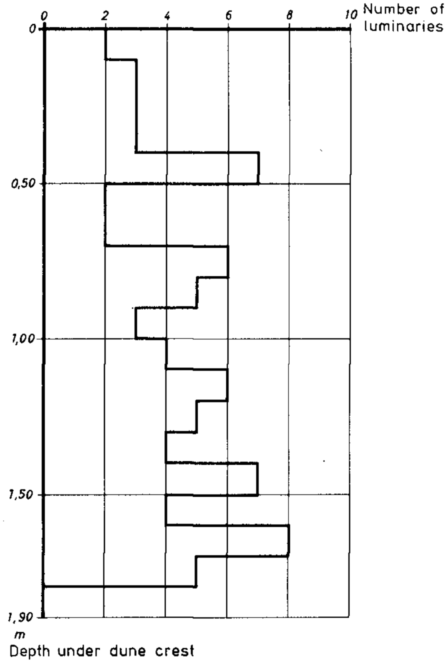


Fig. 5 Luminaries found in a Core Sample taken from Dune Crest app. four Weeks after Start of Tests

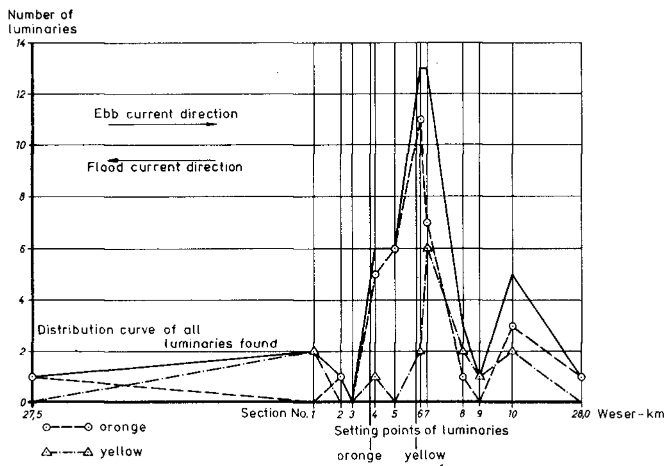


Fig. 6 Luminaries found on the River Bottom app. six Weeks after Start of Tests

up to 22/10/1974 (taking of CS 12). An increased ebb tide current on several days could have led to a stronger alluvium in the lee area of the sand wave and thus to a higher concentration of luminaries in certain extraction depths. The explanation for the presence of the luminaries from the upper surface down to 1.80 m boring depth is, that the material which had been deposited during the ebb tide phase in the lee area, was transported upstream again in part during the following flood tide phase.

As a result of the luminaries at greater depth below the upper surface of the sand waves, the fact is confirmed that the sand transport at tidal sand waves takes place essentially through local redistribution of the bed material.

The extent to which the luminaries had spread on the upper surface in the investigation area about six weeks after their placing on the Weser bottom, was determined by taking soil samples in the axis of the navigation channel between Weser km 25.5 and Weser km 30.0, and in the crest and trough areas of sand waves a to e. No luminaries were found upstream from km 27.5 and downstream from km 28.0. The luminaries found in a limited investigation area have been depicted in Fig. 6. With the exception of the sample in section No. 9 with a total weight of about 220 g, all other soil samples had a total weight of about 1000 g and thus easy to compare.

The result given in Fig. 6 shows clearly, that the investigation material was transported only insignificantly in ebb current direction, even 6 weeks after the start of the field test.

In comparison to the resultant current route in the test reach, the ebb current orientated sand transport in the sand wave field is smaller by decimal powers, as shown by the following. Cross section referred flood and ebb routes "s_f" and "s_e" were determined according to a calculation with mean tide by the Wasser- und Schiffahrtsdirektion Bremen (Waterway and Navigation Authority Bremen) (9). The mean ebb (flood) current velocities v_{em} (v_{fm}) in the discharge cross section result from the integral of the current velocities between the turn of tide points K, divided by the current duration D_f (D_e).

$$v_{fm} = \frac{\int_{K_e}^{K_f} v_f\ (t)\ dt}{D_f} \quad ; \quad v_{em} = \frac{\int_{K_f}^{K_e} v_e\ (t)\ dt}{D_e}$$

The cross section referred flood (ebb) routes are determined with:

$$"s_f" = \int_{K_e}^{K_f} v_f\,(t)\,dt \quad ; \quad "s_e" = \int_{K_f}^{K_e} v_e\,(t)\,dt$$

The residual current results from s_r = "s_e" - "s_f". The following values for s_r result for two Weser reaches below the investigation area are of interest here

Weser	Q_o m^3/s	s_r km/Tide
km 28.4 to 30.9 reach 1, Fig. 1	100 282 600	3.9 7.1 12.3
km 34.5 to 35.5 reach 2, Fig. 1	100 282 600	3.9 6.9 11.4

At a fresh water discharge of only 100 m^3/s, the residual current is already app. 4 km/tide in ebb current direction. The fresh water discharge was $\bar{Q}_o$ = 224 m^3/s in the mean from the beginning of the investigations (18/9/1974) up to the day of the taking of the soil samples (4/11/1974). The short travel distance of the bed material on the surface shows how stable the sand wave covered river bottom is. The investigations with luminaries have shown in total, that the bed material in a sand wave field is transported through local redistribution with the resultant travel velocity of the tidal dunes.

2. The Bed Material

The section-wise executed sieve analyses of the core samples have shown, that the bed material in the interior of the sand waves is not uniform. In Fig. 3, the enveloping grain distribution curves of the analyses of the core samples CS 12 have been depicted (curves A and B). The earlier determined grain distributions of sand wave reaches in the Weser and Elbe Rivers (6), all lie in the medium sand range between enveloping curves A and B.

The tendency is, that the grain distribution curves of the other core samples are similar to those shown in Fig. 3.

The evaluation of the bed material in the soil samples, showed in general with increasing depth, a reduction of the finer components as compared to the coarser material, as also shown by the example of core sample CS 12 (Fig. 7). This result also coincides with earlier investigations on river banks and sand waves, according to which, coarser material is present in the trough areas (5,6,8).

The inconstant distribution in the core samples shows how the transport of fine and coarse bed material, contingent on the time, proceeds over the luff slope of a sand wave to the neighbouring lee slope, as a result of which, the stratification recognizable in Fig. 7 occurs. This time-contingent transport of differing bed material can likewise be responsible, that the number of found luminaries fluctuates in the core sample sections. In order to be able to obtain further information thereon, the grain diameter of the luminaries must also be determined in future measurings.

It must yet be mentioned at this point, that model tests at the Franzius Institute with bed material from sand wave c, have confirmed the alternating stratification of coarser and finer bed material in the interior of the sand wave, despite the changed geometric and hydraulic conditions in the laboratory at stationary current (10).

The fact emerged during the core extractions at sand waves d and e, that beginning at drilling depths which correspond to the elevation of the troughs, a firm clay layer was found. Accordingly, the sand banks in the area under consideration here, migrate over a non-erodable soil, from which no sand waves are formed. This result shows, what importance is attached to objectively executed soundings, before the deepening of a river bottom. It can only then be stated, whether sand wave formation must be figured on after the work is completed, when it is known what type of bed material will be encountered during deepening dredging. If for example, there is a layer of clay present at the trough level of a sand wave reach and a subgrade is created during a deepening through stripping the sand wave, sand waves could only then form after the development measures, if sandy material from outside can penetrate into the deepened river stretch.

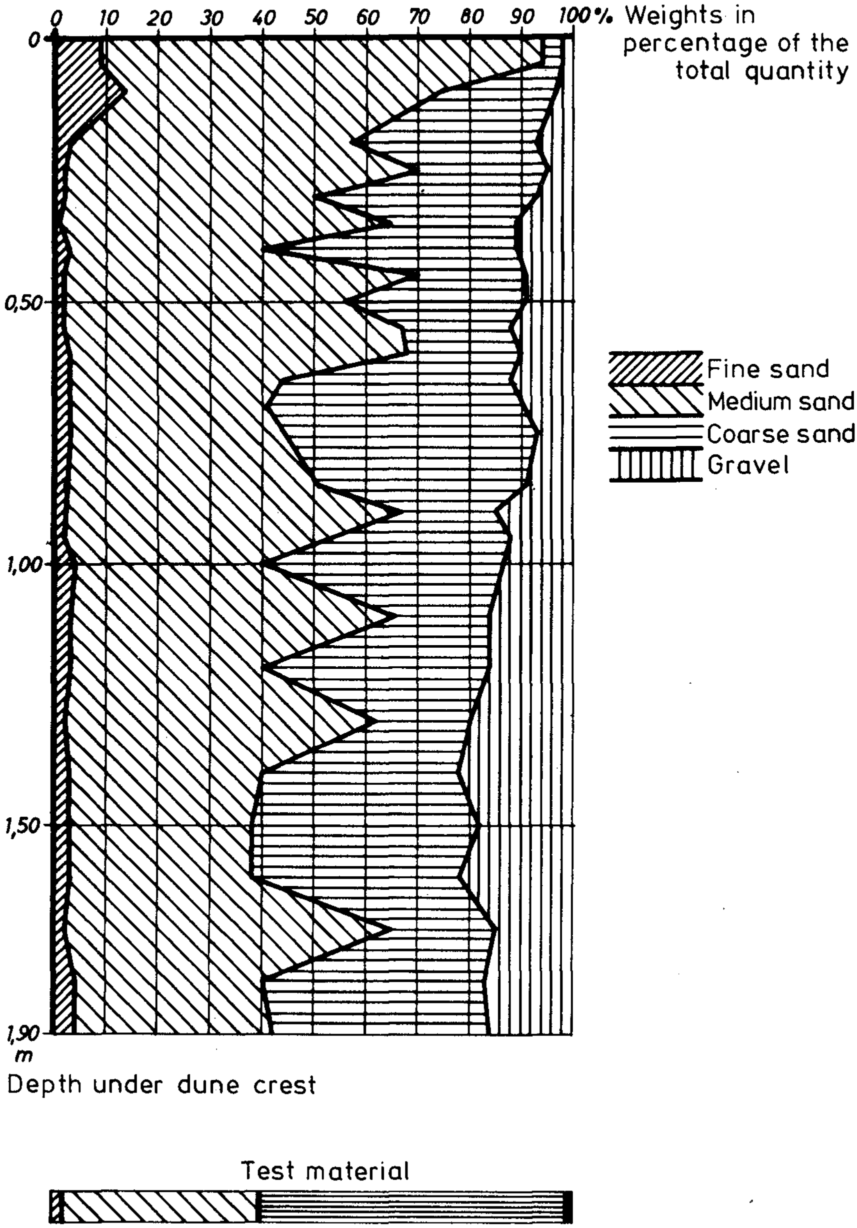


Fig. 7 Core Sample taken from a Dune Crest

IV. Conclusions

The investigations with luminaries in a sand wave reach of the lower Weser River, in good concurrence with theoretical considerations (2,3,4),have shown that the sand transport is effected essentially through local redistribution of the bed material. The resultant sand transport in ebb current direction corresponds to about the migration velocity of the tidal dunes. It emerges from the result, that the regeneration of the sand waves after dredgings and the minimum depths resulting therefrom, are likewise caused by short distance transport. Separate investigations on the regeneration of tidal dunes after dredgings have shown, that the troughs are very stable and that the sedimentation takes place chiefly in the crest area (7). As undesirable water depths are repeatedly encountered also in sand wave reaches of several kilometers length, and the sand transport proceeds only very slowly, the bed material required for the growth of the banks must enter the navigation channel in transverse transport from the embankments and shores. If it could be managed to prevent the continued feeding of bed material from the sides through shore and embankment revetments, it should be possible to considerably lengthen the regeneration time of the tidal dunes solely herefrom.

V. Acknowledgement

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